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Paper 1

Effects of Natural Stream Channel Changes on Streamflow Measurement

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WATER RESOURCES
PAPER 1

EFFECTS OF NATURAL STREAM CHANNEL CHANGES ON STREAMFLOW MEASUREMENT

By

J. W. Quick and
F. C. Fleischer

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EFFECTS OF

NATURAL STREAM CHANNEL CHANGES ON

STREAMFLOW MEASUREMENT

INTRODUCTION

In order to assess a proposed streamflow gauging site, or to evaluate the reliability of data collected from an existing streamflow gauging station, it is necessary to take into account the physical characteristics of the stream channel and changes that may have occurred with time.

The changing of the shape of a stream channel at a control or in the pond upstream of the control caused by natural phenomena, alters the streambed pattern and consequently the hydraulic relationship of streamflow and water-level stage. The most significant changes are caused by erosion, sediment transport and deposition, ice formation and vegetative channel growth.

These changes are generally slow, continuous processes, becoming accelerated and abrupt occasionally during the year. They may follow a general trend for a particular river, or they may be peculiar to a specific gauging site. Each basin is characterized by such factors as land cover, topography, soil type and drainage characteristics, governing the gradient of the stream; combined with the

characteristics of precipitation patterns, they govern the volume and the velocity of streamflow. These factors in turn govern the changes and changing processes at a streamflow gauging station.

This paper illustrates some of the results of analyses of streamflow data collected from the study of representative basins, which forms part of the Ontario Water Resources Commission's contribution to the International Hydrological Decade (IHD) program.

RELATIONSHIPS OF STREAMFLOW MEASUREMENT

Streamflow data collection is a computational procedure based on direct measurements of water-level stage and discharge. The velocity-area method is commonly used to measure discharge, while stage is most efficiently measured by a continuous water-level recorder. Measurement of streamflow is the establishment of the relationship between the velocity and area of flow and the water level and the application of this relationship to continuous or individual fluctuations in stage to obtain records of discharge.

Velocity of Flow

Velocities of flow are measured using standard current meters. Each meter is calibrated by the manufacturer and supplied with a rating table showing the variation of velocity with the number of revolutions of the meter. For each revolution or number of revolutions in a specified period of time, the velocity is a pre-determined value; however, the velocity could become erroneous if points such as the following are overlooked:

1. The meter should be held as parallel to flow as possible.
2. The meter should be used for the purpose for

which it was designed (limitations are depth and velocity of stream).

3. The meter should be maintained in proper working order (cleaned, well oiled, badly worn bearings replaced, etc.).
4. Timing should be exact according to the specifications for a particular meter (e.g. revolutions should be counted for the exact time intervals specified, or interpolation becomes necessary).
5. A turbulent metering section should not be used.

Velocity and Discharge

Considering the parameters of streamflow measurement, discharge is governed by the following relationships:

1. Width x Depth = Area (cross-sectional area of flow)
   (feet) x (feet) = (square feet)

2. (Meter Revolutions ÷ Time) x Factor = Velocity (of flow)
   (revolutions ÷ seconds) x factor = (feet per second)

3. Velocity x Area = Discharge (discharge of stream)
   (feet per second) x (square feet) = (cubic feet per second)

The parameters of area influence the factors of velocity and consequently the discharge.

The cross-sectional area and consequently the water-level stage are governed by the streambed control, whether a natural channel control or an artificial control (e.g. concrete weir). If the control remains of constant shape and elevation, a constant relationship of stage to discharge can be derived; however, if an alteration to the control occurs, i.e. a change occurs in the shape or the effective cross-section of the channel, then the stage-discharge relationship cannot be expected to remain constant.

In practice, an attempt is made to obtain a constant stage-discharge relationship for each gauging site. By obtaining a continuous stage record at each station, continuous discharges can then be computed. To avoid complicated changes in station 'rating curves' (stage-discharge relationships), it is desirable to minimize the possibility of occurrence of any changes in channel shape.

EFFECTS OF CHANNEL CHANGES
ON STREAMFLOW CHARACTERISTICS

Channel changes occurring at a streamflow gauging station with a natural control can become critical if the changes alter the shape of the control or controlling section. The effects of channel changes appear as follows:

(a) At the control (discharge constant):

1) Increasing the elevation creates

   i. a deeper pond, if existent,
   ii. an increase in stage upstream of the control,
   iii. a possible decrease in velocity upstream of the control.

2) Decreasing the elevation creates

   i. a shallower pond,
   ii. a decrease in stage,
   iii. a possible increase in velocity upstream of the control.

3) Increasing the width creates

   i. a shallower pond,
   ii. a decrease in stage,
   iii. a possible decrease in velocity at the control.

4) Decreasing the width creates

   i. a deeper pond,
   ii. an increase in stage,
   iii. a possible increase in velocity at the control.

The above-mentioned changes may be difficult to detect at the control and in some cases can be more readily

identified by studying the variations in relationships of streamflow parameters at the metering section.

In addition, effects of increasing and decreasing elevation and width of the pond or streambed upstream of the control can also become significant in the interpretation of data from the station; however, the effects of these changes are usually similar to those that occur at the metering section of the stream.

(b) At the metering section (discharge constant):

1) Increasing the elevation of the streambed creates

   i. an increase in stage at the section,
   ii. a possible increase in velocity.

2) Decreasing the elevation of the streambed creates

   i. a decrease in stage at the section,
   ii. a possible decrease in velocity.

3) Increasing the width of the section creates

   i. a decrease in stage,
   ii. a possible decrease in velocity.

4) Decreasing the width of the section creates

   i. an increase in stage,
   ii. a possible increase in velocity.

A combination of the above changes and effects usually occurs at locations with natural controls, creating a cumulative effect on the stage-discharge relationship.

As a natural stream channel and control do not commonly take a precise rectangular shape, an increase or decrease in the elevation of the control may not necessarily cause the same increase or decrease in stage. A characteristic relationship exists for each control section, natural or artificial. Measurements of velocity, area and stage are necessary to define this relationship and the modifications created as the channel geometry changes.

CASE STUDIES

In order to study the effect of a change in a stream channel on the streamflow patterns, station B-2, in the Bowmanville, Soper and Wilmot creeks basin, was chosen; it has a natural control, a poor stage-discharge rating curve and an occasionally silting pond (see Figure A). For a comparison, two other stations in the same basin were selected, namely station W-3 and station S-2 (see figures B and C; the locations of the stations described are shown on Map 1). These two stations have artificial control structures and exhibit well-defined stage-discharge relationships. Taking individual streamflow measurements, including data on area and velocity at the metering sections and stage (water level) readings, an attempt was made to describe the relationships that appear to exist between the parameters of streamflow at the three stations. Data for station W-3 and S-2 were plotted as a comparison to the data for station B-2.

Attached are the following comparative plots for stations B-2, W-3 and S-2:

Figures I A, B, C	Velocity vs. Area of Flow
Figures II A, B, C	Velocity vs. Discharge
Figures III A, B, C	Area of Flow vs. Discharge
Figures IV A, B, C	Stage vs. Discharge

The parameters of velocity, area and discharge were determined by actual field measurement with standard current metering equipment. The velocity of flow (feet per second) is the average velocity at the metering section, derived by dividing the total discharge (cubic feet per second) by the area (square feet) of the stream cross-section at the point of measurement.

<u>Velocity vs. Area of Flow</u>

Under conditions of constant discharge and a stable channel, an inverse relationship of velocity to sectional area of flow should exist. Theoretically, an increase in the area of a metering section should cause a decrease in the velocity and a decrease in the area should produce a corresponding increase in velocity, the discharge remaining constant.

Under conditions of varying discharge with time, a general trend in the velocity-area relationship should become evident. As natural changes in the stream-channel characteristics occur, a shift in the trend would show varying velocities for similar areas of flow.

In examining Figure I A, illustrating the relationship of velocity to area at the metering section of the natural control station B-2, a clear trend is evident.

For the range of flows less than approximately seven cfs, a general downward trend is shown for area with increasing velocity. It appears logical to assume that a change in the stream-channel shape has occurred in this instance, as evident from the apparent decrease in area. Field observations have indicated shifts in the streambed profile due to silting and movement of sand and gravel bars.

On examining the velocity-area relationship for stations W-3 and S-2 (figures I B and I C), generally increasing trends in area and velocity are evident for increasing discharge ranges.

Station W-3 (Figure I B) exhibits a well-defined relationship in the low flow range of approximately 0 - 10 cfs; however, some scatter occurs in the higher flow ranges.

The measurements taken at other than the regular metering section (see Figure I B) do not plot on the velocity-area curve for the regular section. Measurement number 28, although taken at the regular section, plots extraneously because of the lower average velocity produced as the high flow rose above the defined channel banks.

Station S-2 (Figure I C) exhibits abnormal scatter in the low flow range of approximately 0 - 10 cfs,

showing a variation in area of approximately three square feet for the same discharge. Field observations have revealed meandering of flow channels within the defined stream channel; however, no significant change in streambed elevation appears to have occurred at the section.

Velocity vs. Discharge

All three stations exhibit a generally consistent trend for the velocity-discharge relationship (see figures II A, II B and II C). At station B-2, at low discharges (less than 10 cfs), relatively large changes in velocity occur for relatively small changes in discharge. This relationship is governed by the shape of the channel or the controlling section.

Above flows of 10 cfs, the velocity-discharge curve for station B-2 tends to exhibit an increasing amount of scatter; this suggests a variable relationship of area to velocity at higher flows and is supported by the fact that streambed erosion and deposition occur periodically.

In an attempt to delineate a channel change at station B-2, a study of the velocity-discharge relationships does not appear to reveal any strongly conclusive evidence for such a change.

The velocity-discharge relationship for station W-3 (Figure II B) is similar to that for station B-2 in the lower stages. In the higher stages, station W-3 exhibits a higher rate of velocity increase with increasing discharge.

Examining the velocity-discharge relationship for station S-2 (Figure II C), two distinct curves are evident. Curve No. 1 was developed from data collected prior to the construction of the broad-crested artificial control in May, 1967. Curve No. 2 shows how the installation of the artificial control has affected the velocity-discharge relationship at the metering section, which is located approximately 20 feet upstream from the control. The greater rate of increase in discharge with increasing velocities in the lower discharge stages of this station, as compared to those of station B-2 and W-3, is likely due to the steeper gradient of the streambed at station S-2, providing greater discharges for similar areas of flow.

Area of Flow vs. Discharge

On examining Figure III A for station B-2, it is evident that unusual scatter in area of flow exists for similar discharges for the low flow range of 0 - 10 cfs. The previously examined Figure II A shows that velocities

also vary somewhat for this range of flow, exhibiting variable velocities for similar discharges. These facts combined, tend to indicate varying conditions in channel shape.

The amount of scatter evident in the area-discharge relationships for stations W-3 and S-2 (figures III B and III C), in the relatively low stages, is not as extensive as it is for station B-2. This fact would tend to indicate more stable channel sections at stations W-3 and S-2.

Stage vs. Discharge

As evident from the stage-discharge curve plots for station B-2 (Figure IV A), a shifting in the relationship has occurred. From November, 1965, to June, 1970, there appears to be a downward shift in the elevation of the control, resulting in increased discharges for the same stage.

Well defined stage-discharge relationships exist for stations W-3 and S-2 (figures IV B and IV C); however, more measurements are needed to better define the upper sections of the curve for station S-2. The artificial controls at these two stations appear to be functioning satisfactorily, providing stable relationships of stage-discharge. The minor scatter evident in the plots is

assumed to be due to inherent error in measurement and erroneous effects caused by ice conditions.

CONCLUSIONS

1. Upon examining the parametric relationships of streamflow at a gauging station having a natural streambed or channel control, it appears that any lack of correlation of, or a variable inter-relationship among the parameters of area, velocity and discharge, can be attributed to physical changes that occur in the channel shape. Accordingly, geometric channel changes may be detected by obtaining streamflow measurements and plotting the following relationships:

(a) velocity vs. area of flow
(b) area of flow vs. discharge
(c) stage vs. discharge

From the stations chosen for this study, it appears that the velocity-area and stage-discharge plots are more useful than the area-discharge plots as means of deducing changes in channel shape.

2. It appears that a plot of the velocity-discharge relationship for a station may not reveal any conclusive evidence of a geometric channel change.

3. In examining the plots, it appears that significant channel changes have occurred at either the metering section or the control at station B-2. Because of the proximity of the control to the metering section,

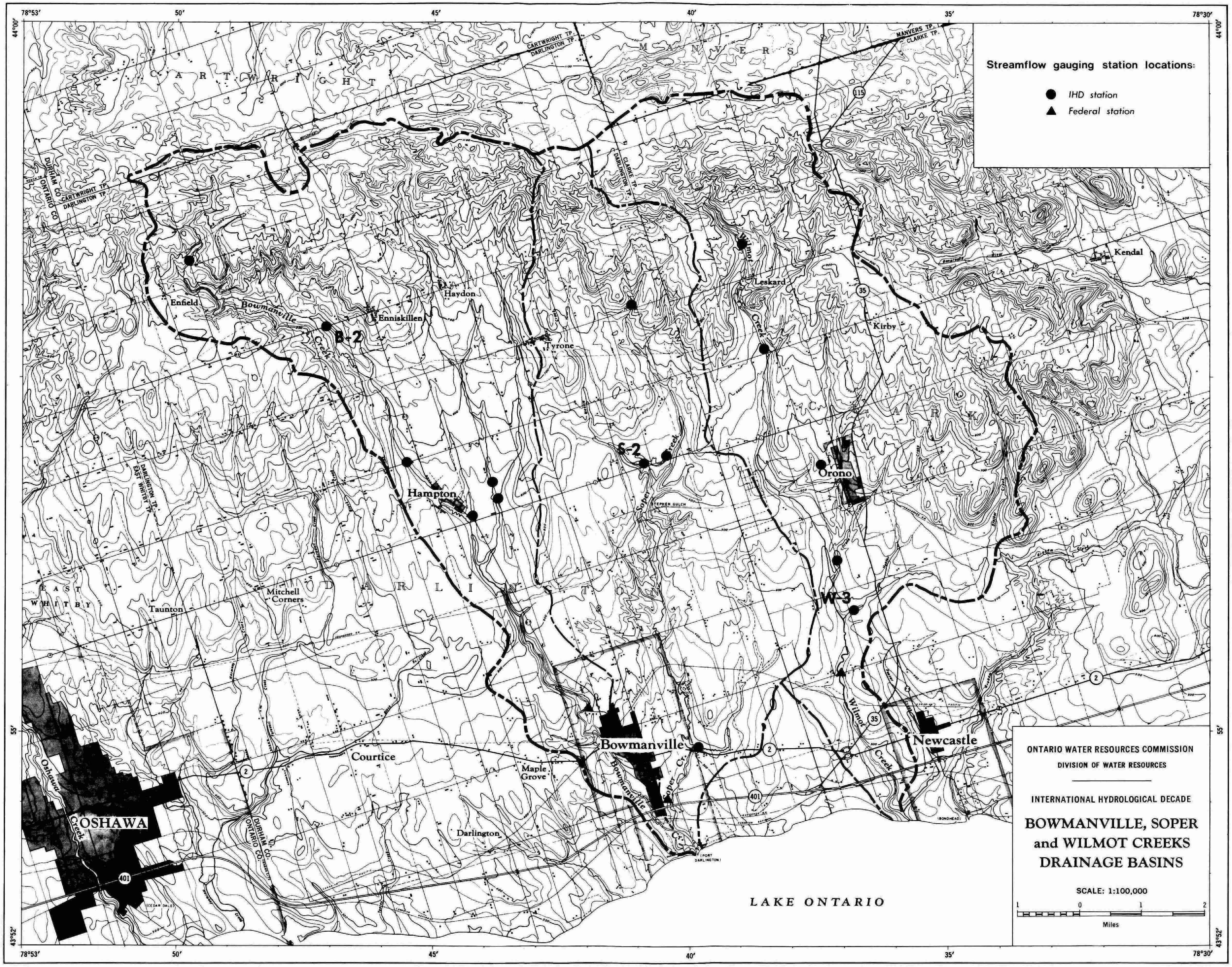
any significant changes at the control would likely cause significant variation in the parameter relationships at the metering section. Examining the stage-discharge relationship for station B-2, it is evident that physical changes have occurred at the natural channel control. In addition, channel changes have occurred at the metering section of station B-2, as evident from the velocity-area relationship.

4. The velocity-area relationship for station S-2 indicates minor streambed changes at the metering section. These, however, do not appear to have affected the rating of the station, as indicated by the stable stage-discharge relationship. The changes that have occurred at this station are therefore considered insignificant.

5. The construction of the artificial control at station S-2 definitely altered the parametric relationship of velocity to discharge existent at the metering section prior to the construction.

6. The parametric relationships for station W-3 indicate relatively stable channel conditions as determined at the metering section.

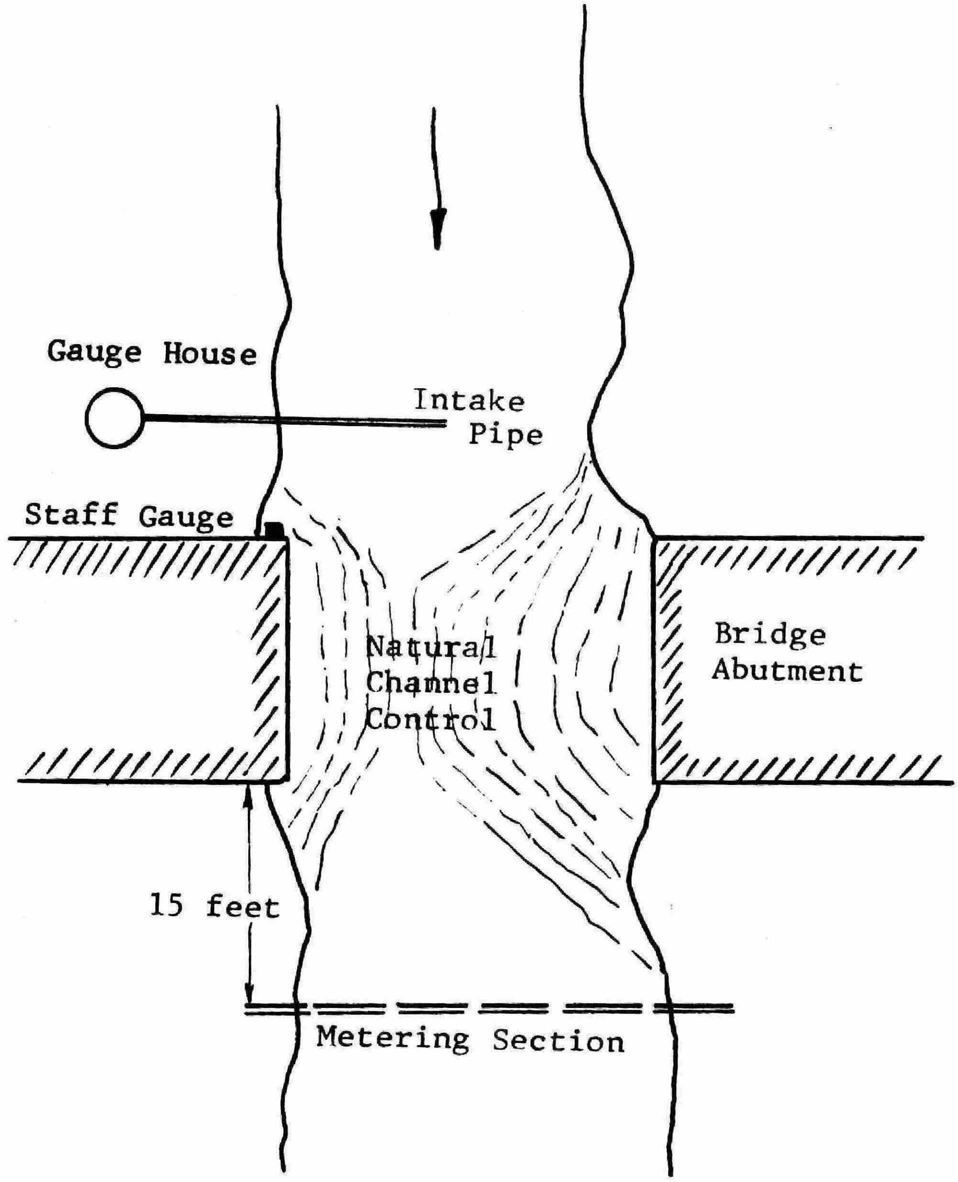
7. In using streamflow measurement data to evaluate streamflow gauging station behaviour, care should be taken to use the same metering section for each measurement.



Map 1: Streamflow Gauging Station Locations

FIGURE A

Station B-2



PLAN VIEW, STATION B-2

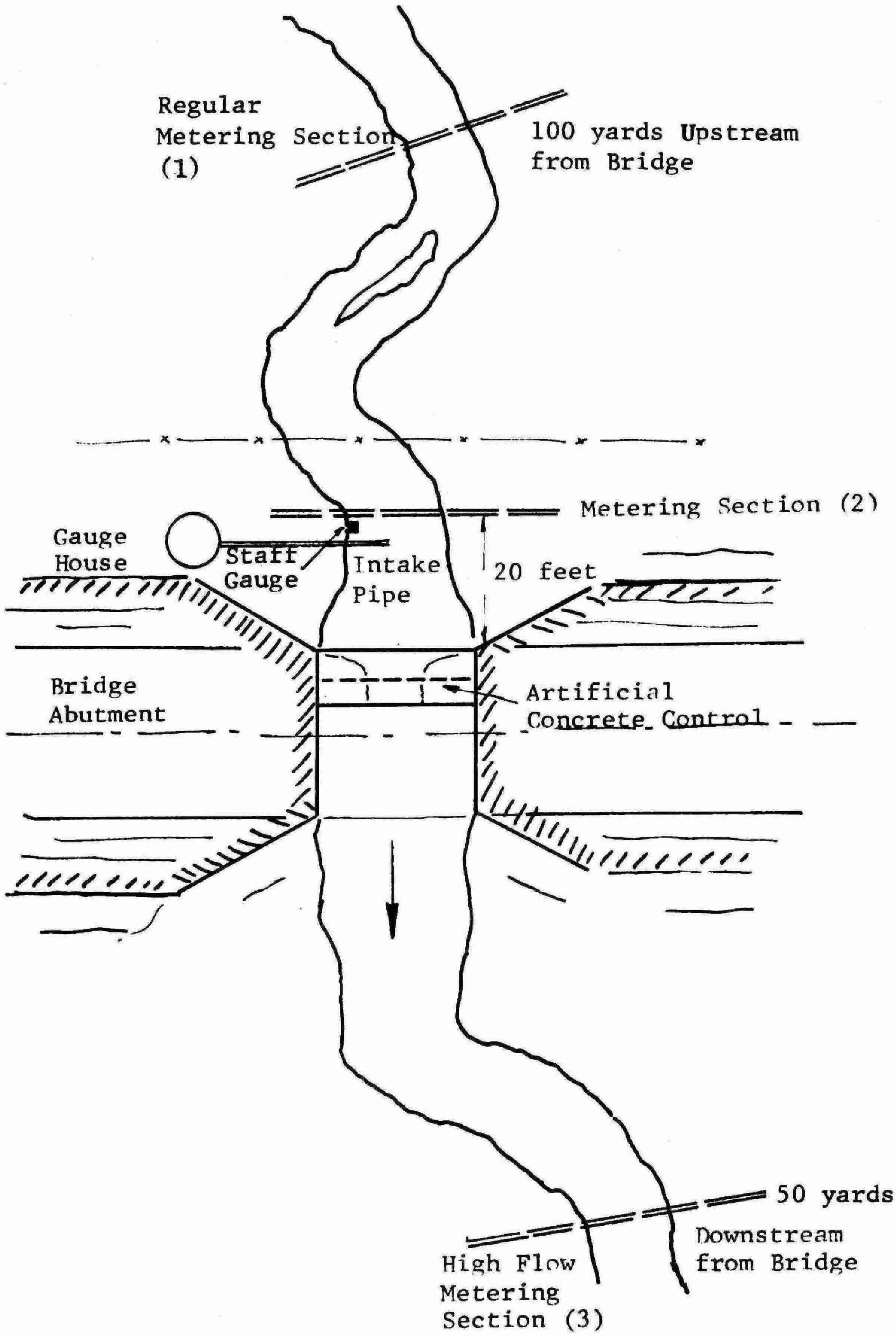
Natural channel control under bridge.

Metering section, downstream of bridge.

STATION B-2

FIGURE B

Station W-3

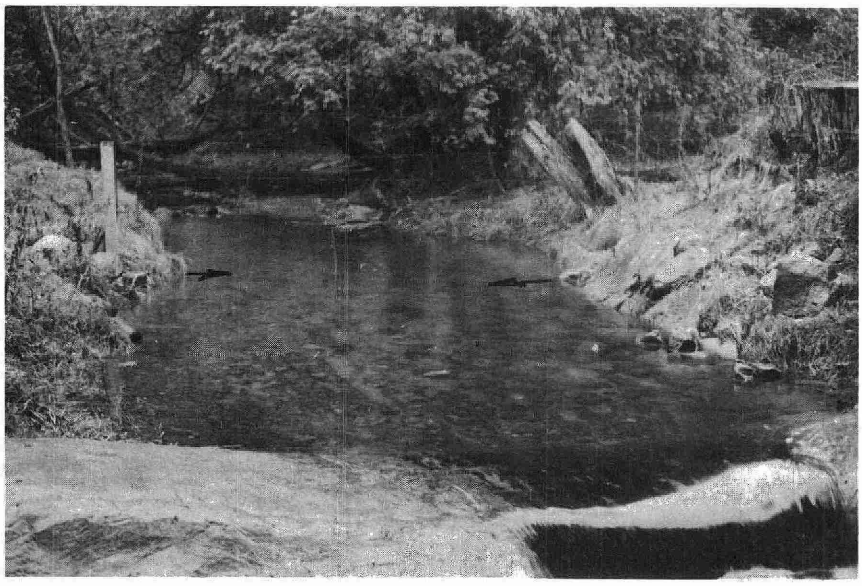


PLAN VIEW, STATION W-3

Artificial concrete control (capped gabion baskets).

Regular metering section.

STATION W-3



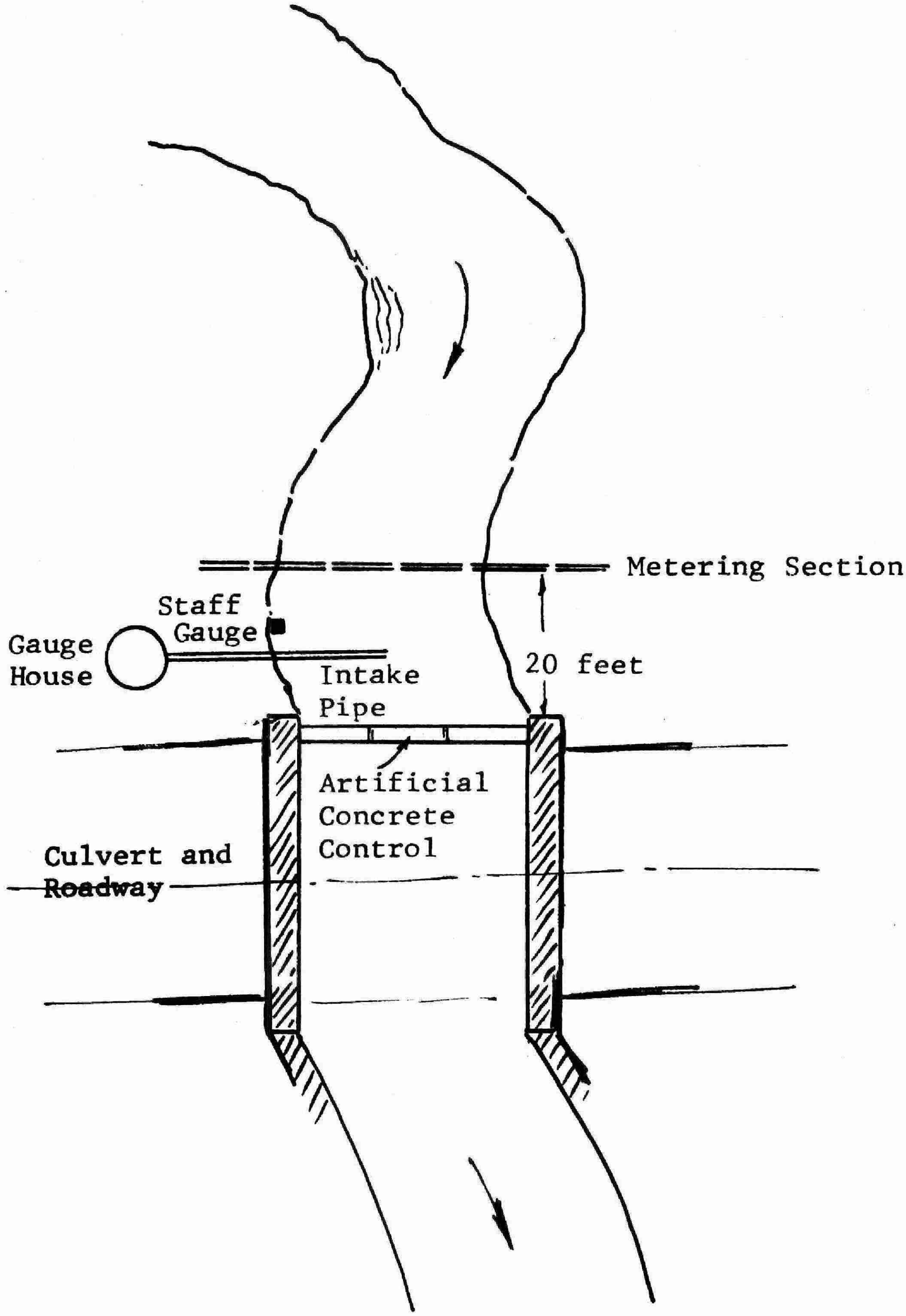
Alternate metering section, upstream of control.

High flow metering section downstream of bridge.

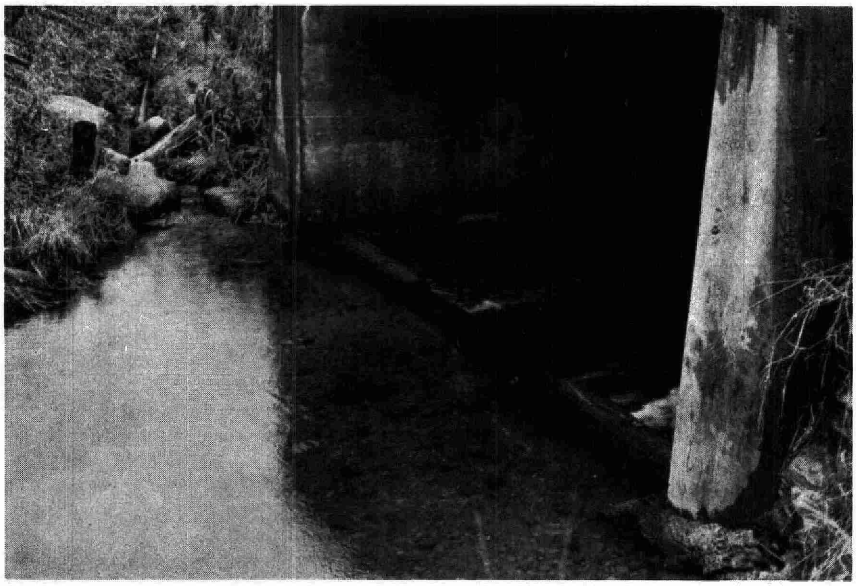
STATION W-3

FIGURE C

Station S-2



PLAN VIEW, STATION S-2



Artificial concrete control (broad-crested Cipolletti).

Metering section, upstream of culvert.

STATION S-2

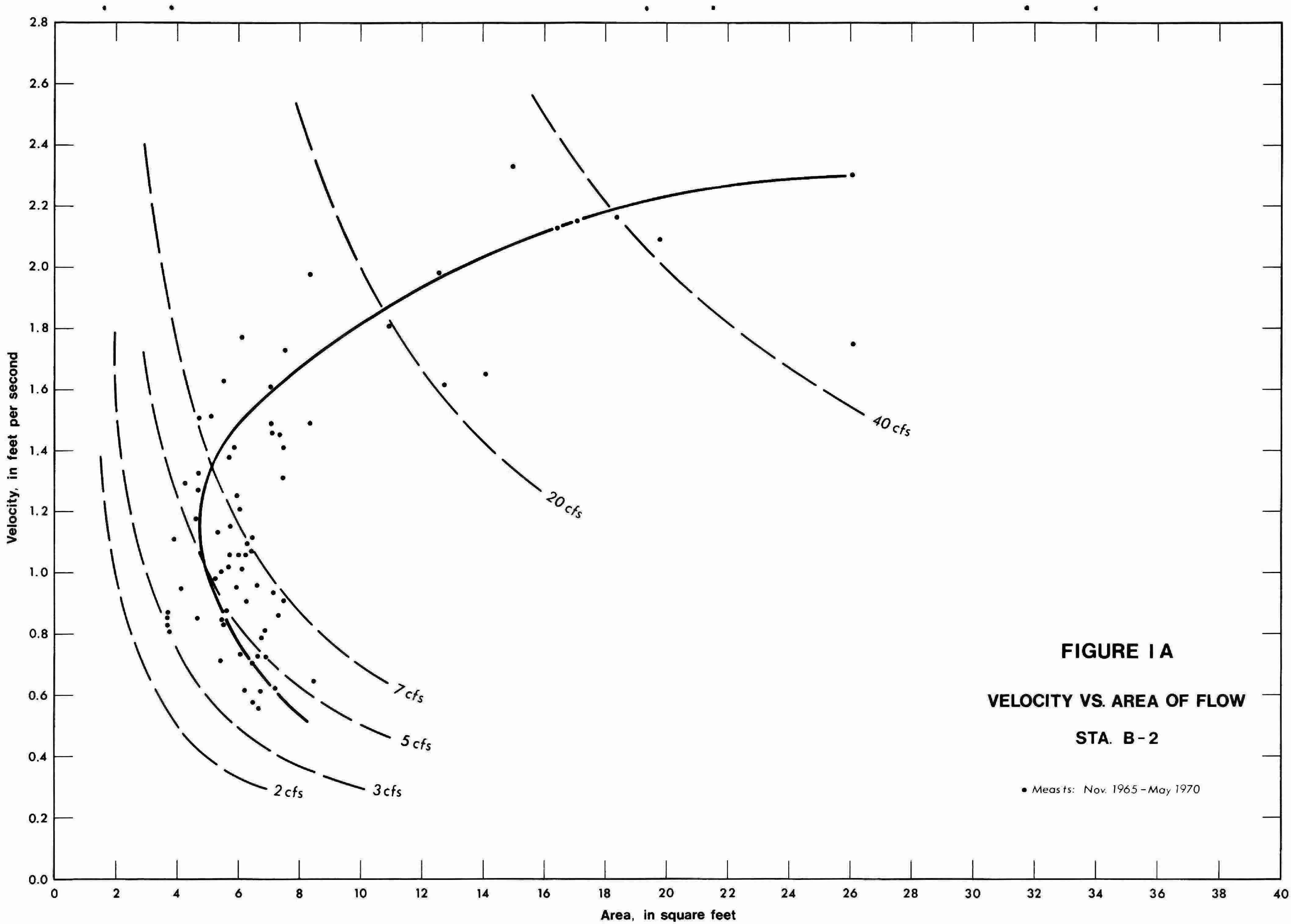


FIGURE I A
VELOCITY VS. AREA OF FLOW
STA. B-2
• Meas ts: Nov. 1965 – May 1970
2 cfs
3 cfs
5 cfs
7 cfs
20 cfs
40 cfs
Velocity, in feet per second
Area, in square feet

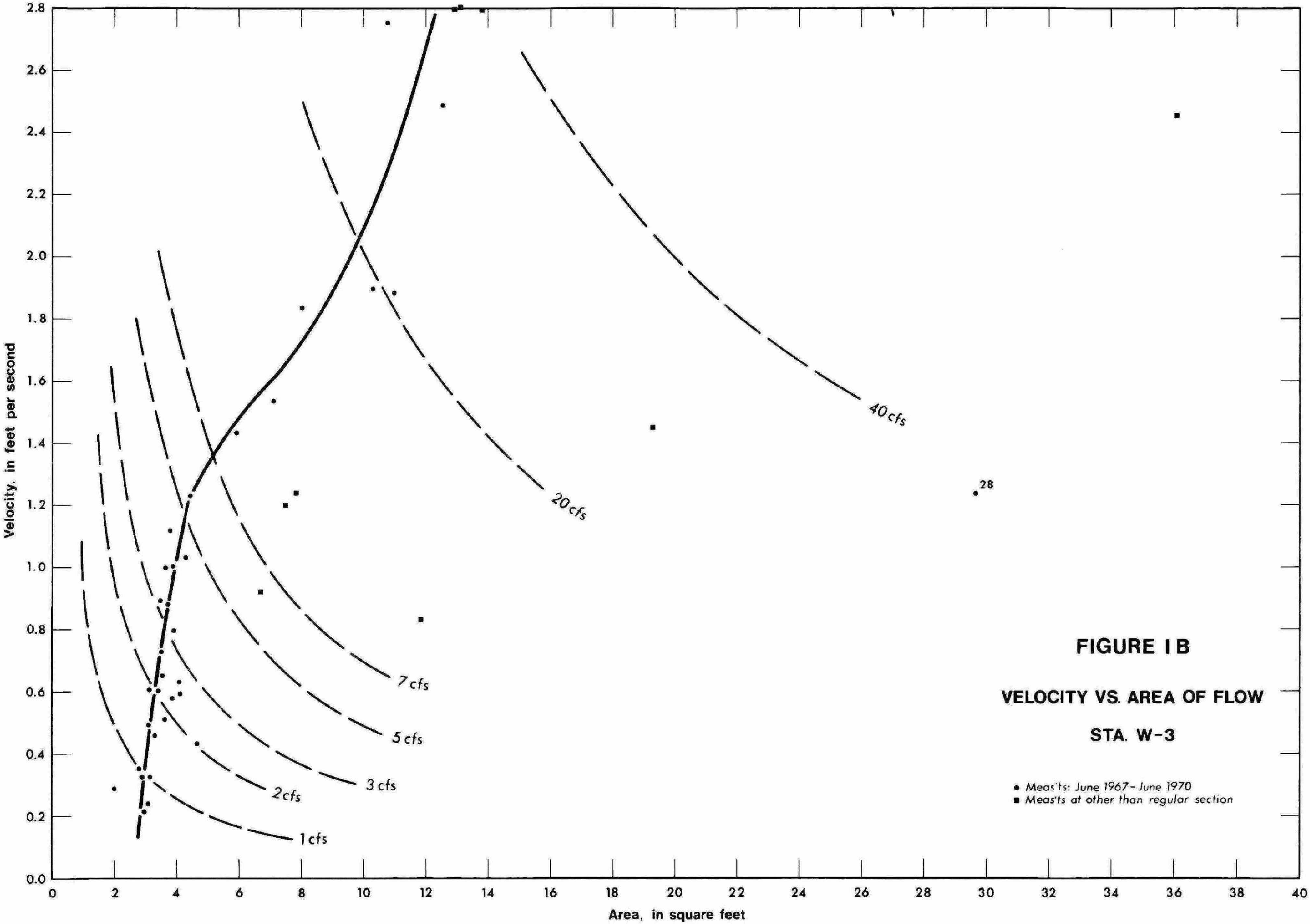


FIGURE 1B

VELOCITY VS. AREA OF FLOW

STA. W-3

- • *Meas'ts: June 1967 – June 1970*
- ■ *Meas'ts at other than regular section*

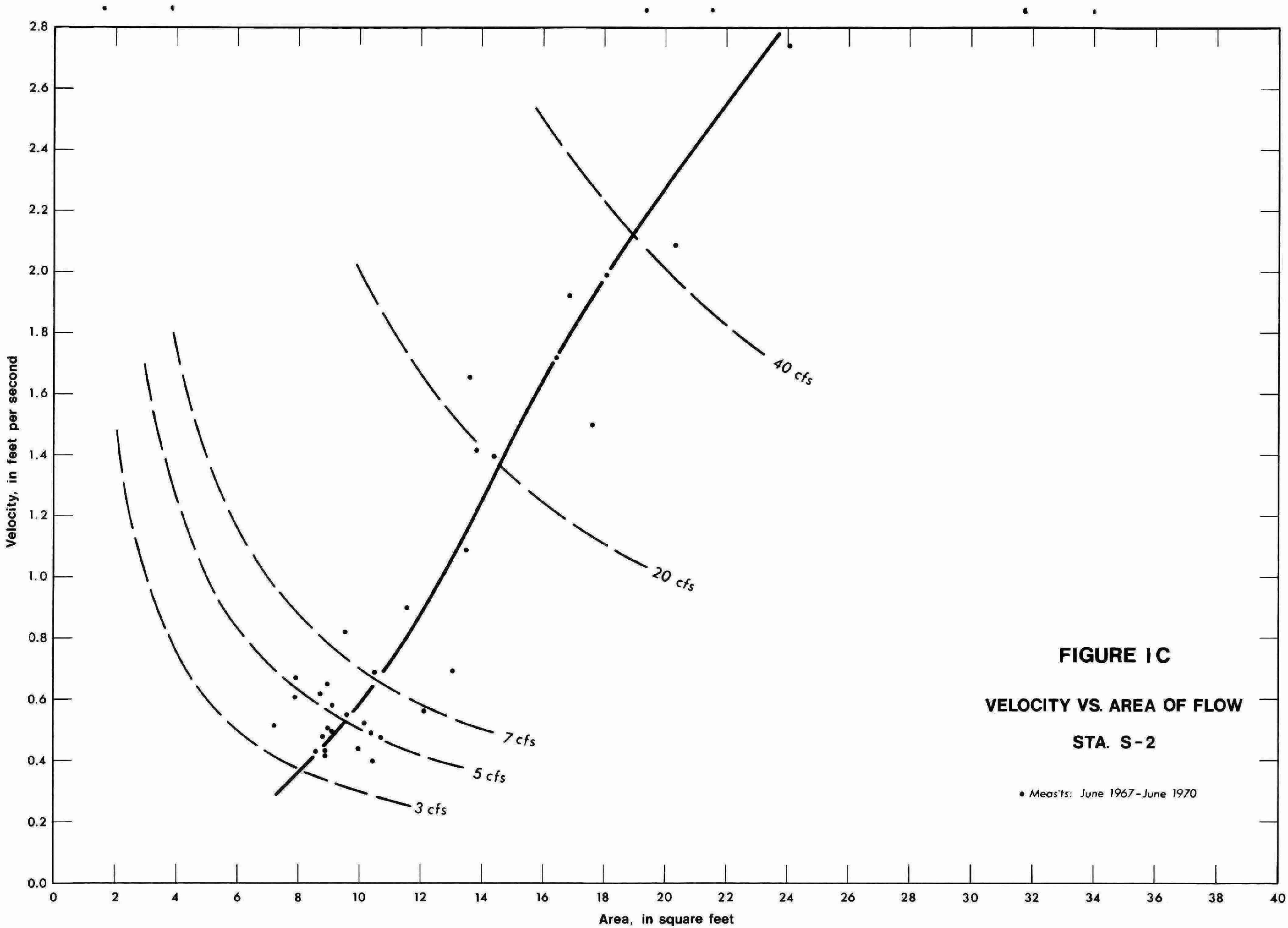


FIGURE 1C

VELOCITY VS. AREA OF FLOW

STA. S-2

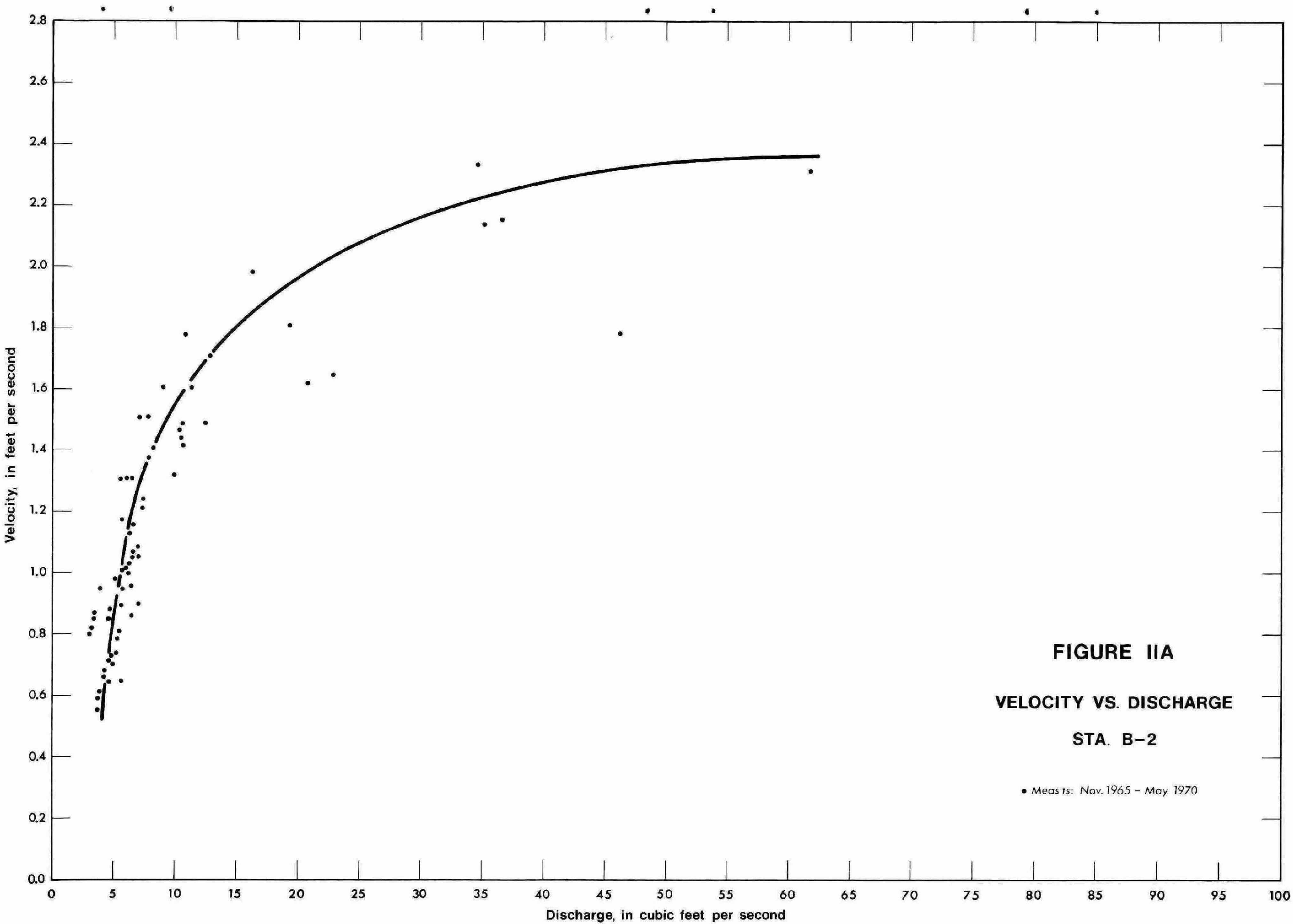


FIGURE IIA
VELOCITY VS. DISCHARGE
STA. B-2
• Meas'ts: Nov. 1965 – May 1970
Velocity, in feet per second
Discharge, in cubic feet per second
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

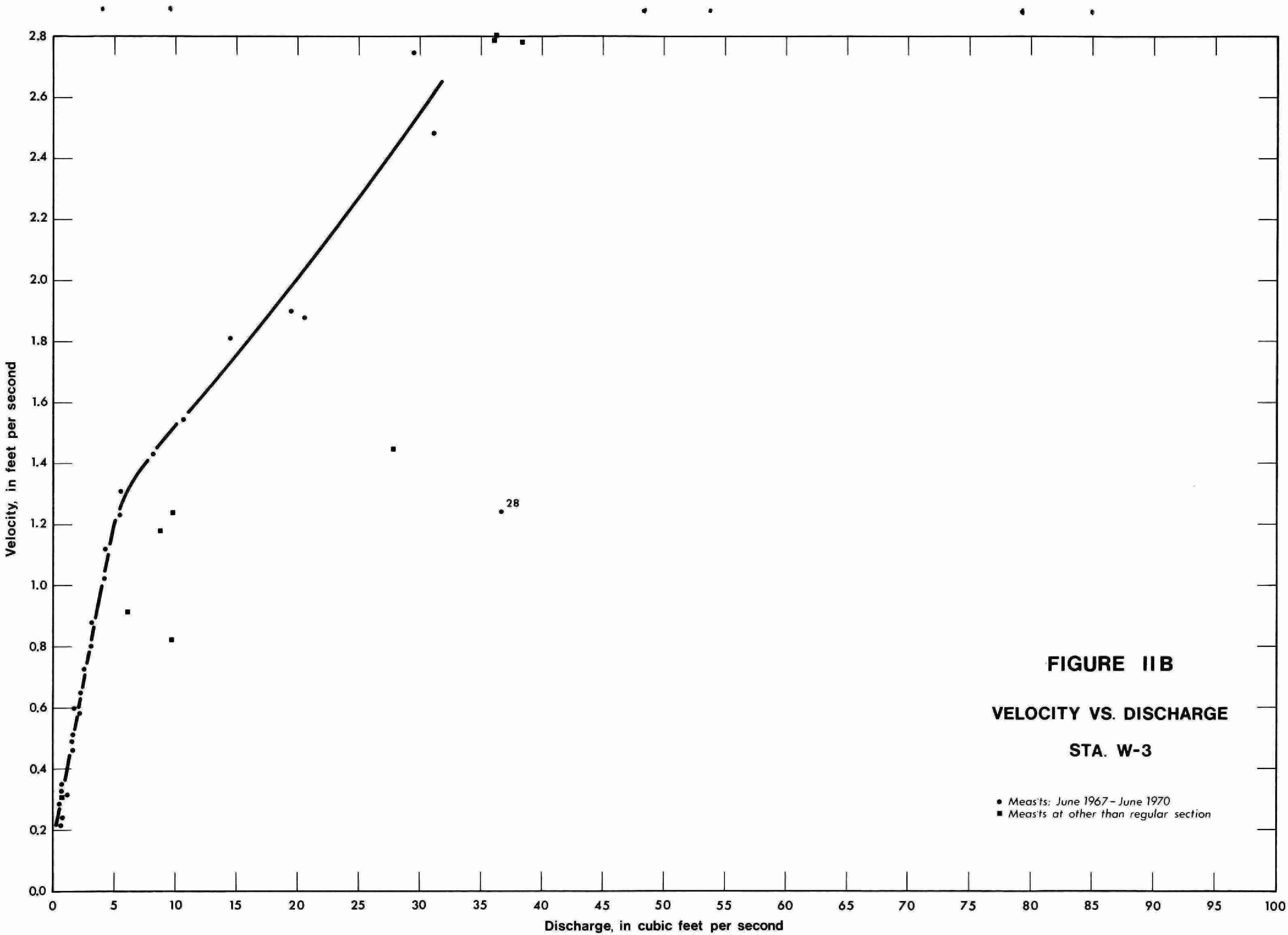
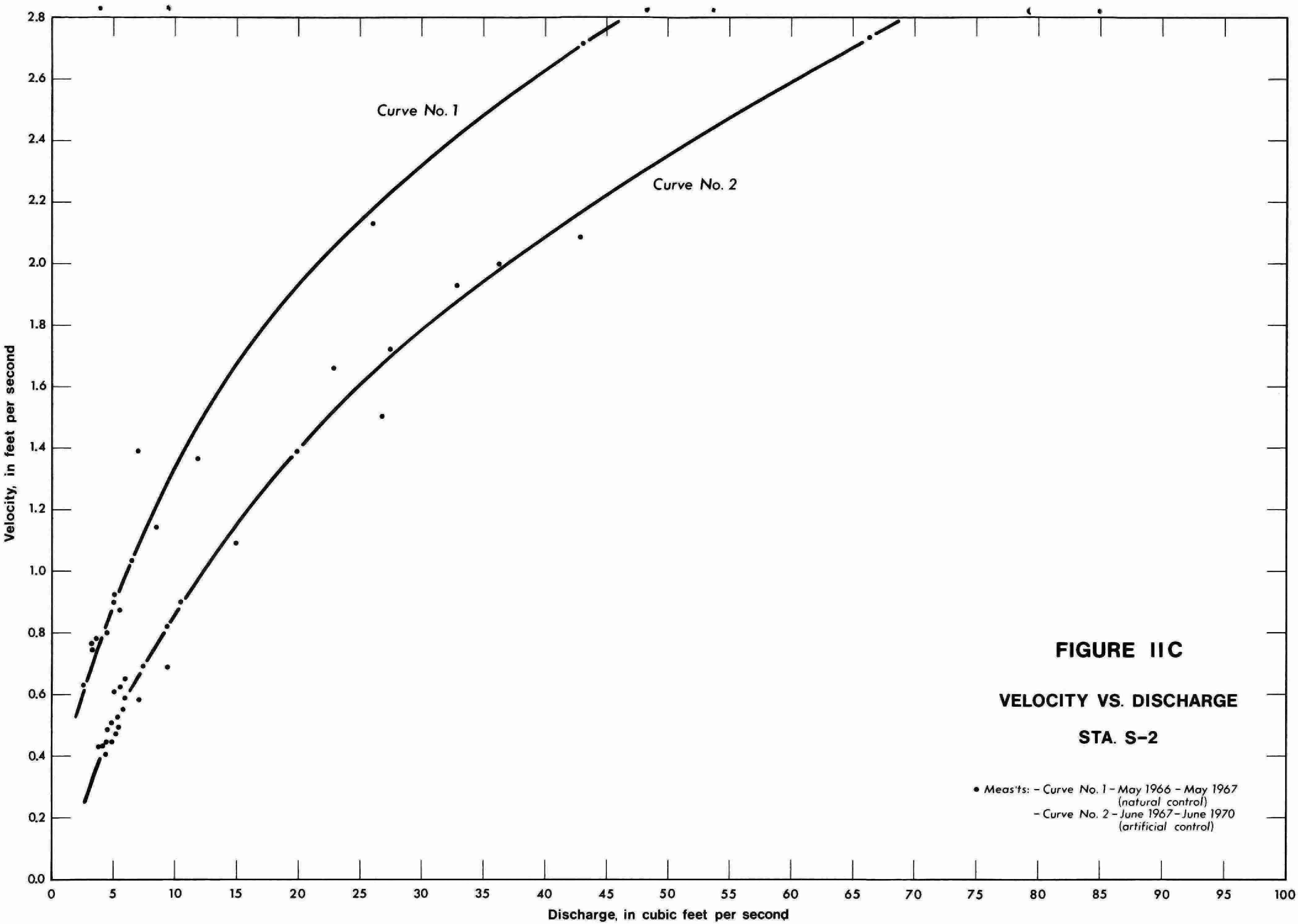


FIGURE IIB

VELOCITY VS. DISCHARGE

STA. W-3


Curve No. 1
Curve No. 2
Velocity, in feet per second
Discharge, in cubic feet per second
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
FIGURE IIC
VELOCITY VS. DISCHARGE
STA. S-2
• Meas'ts: - Curve No. 1 - May 1966 - May 1967
(natural control)
- Curve No. 2 - June 1967 - June 1970
(artificial control)

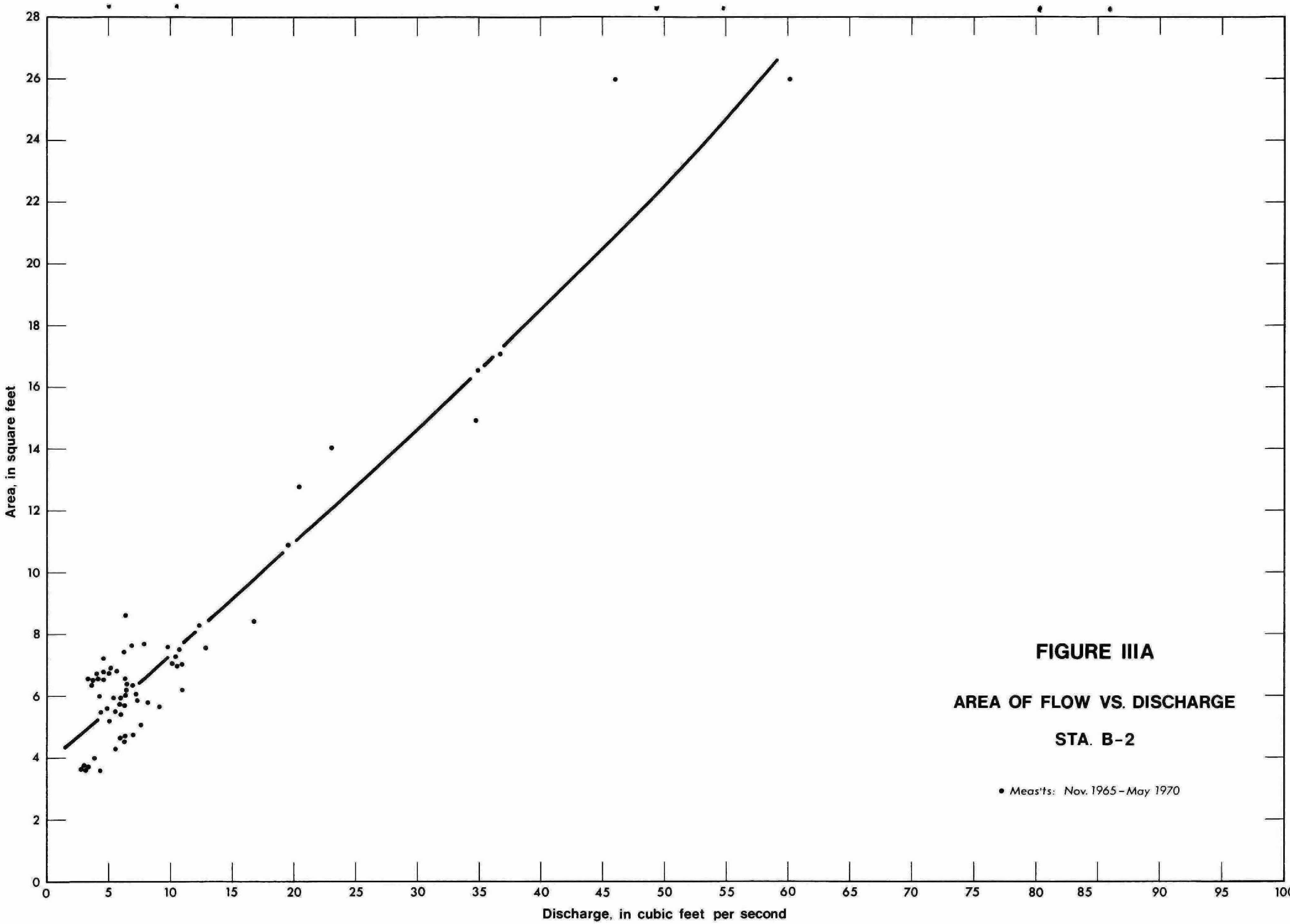


FIGURE IIIA
AREA OF FLOW VS. DISCHARGE
STA. B-2
• Meas'ts: Nov. 1965 – May 1970
Area, in square feet
Discharge, in cubic feet per second
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

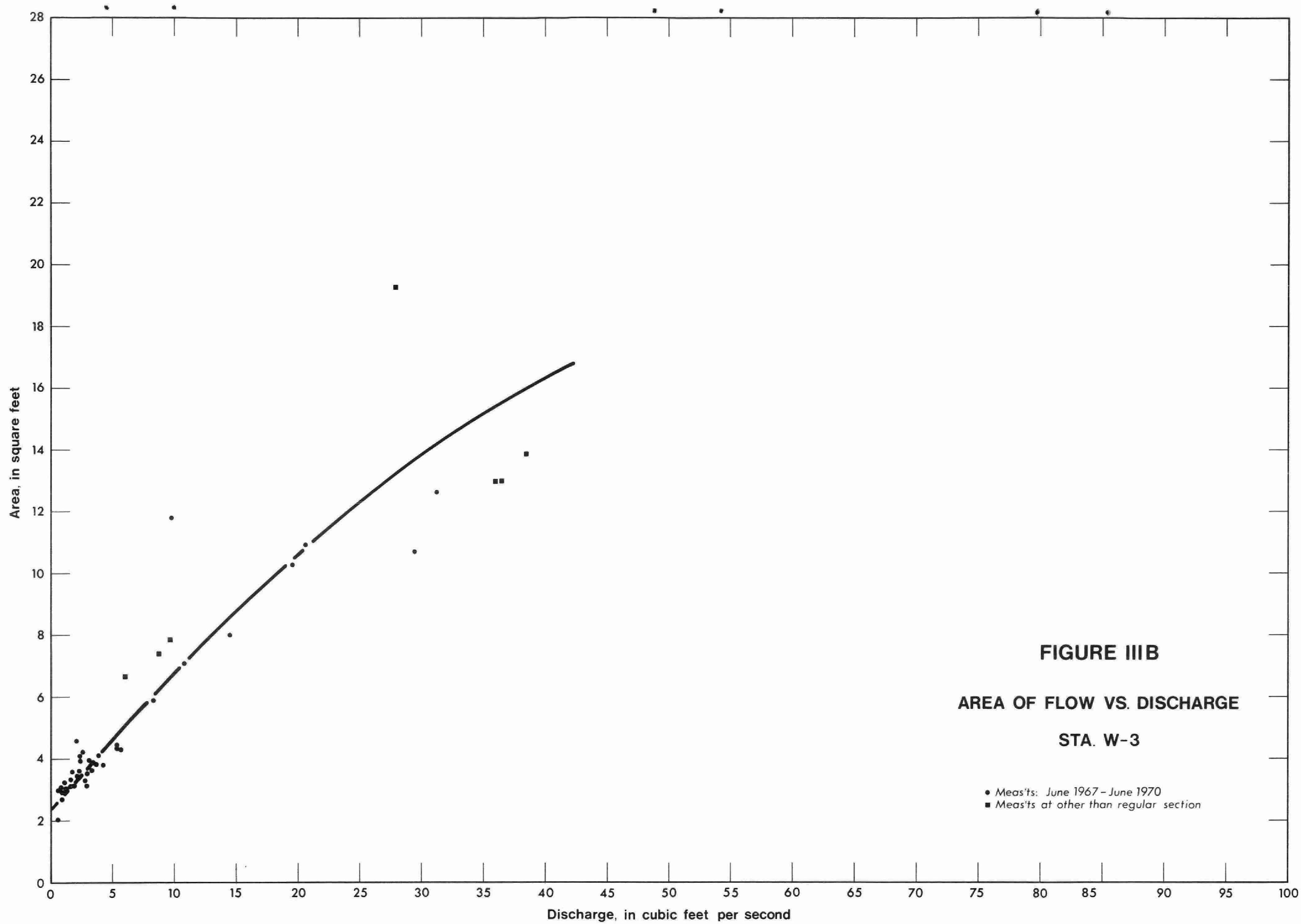


FIGURE IIIB
AREA OF FLOW VS. DISCHARGE
STA. W-3
• Meas'ts: June 1967 – June 1970
■ Meas'ts at other than regular section
Area, in square feet
Discharge, in cubic feet per second
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

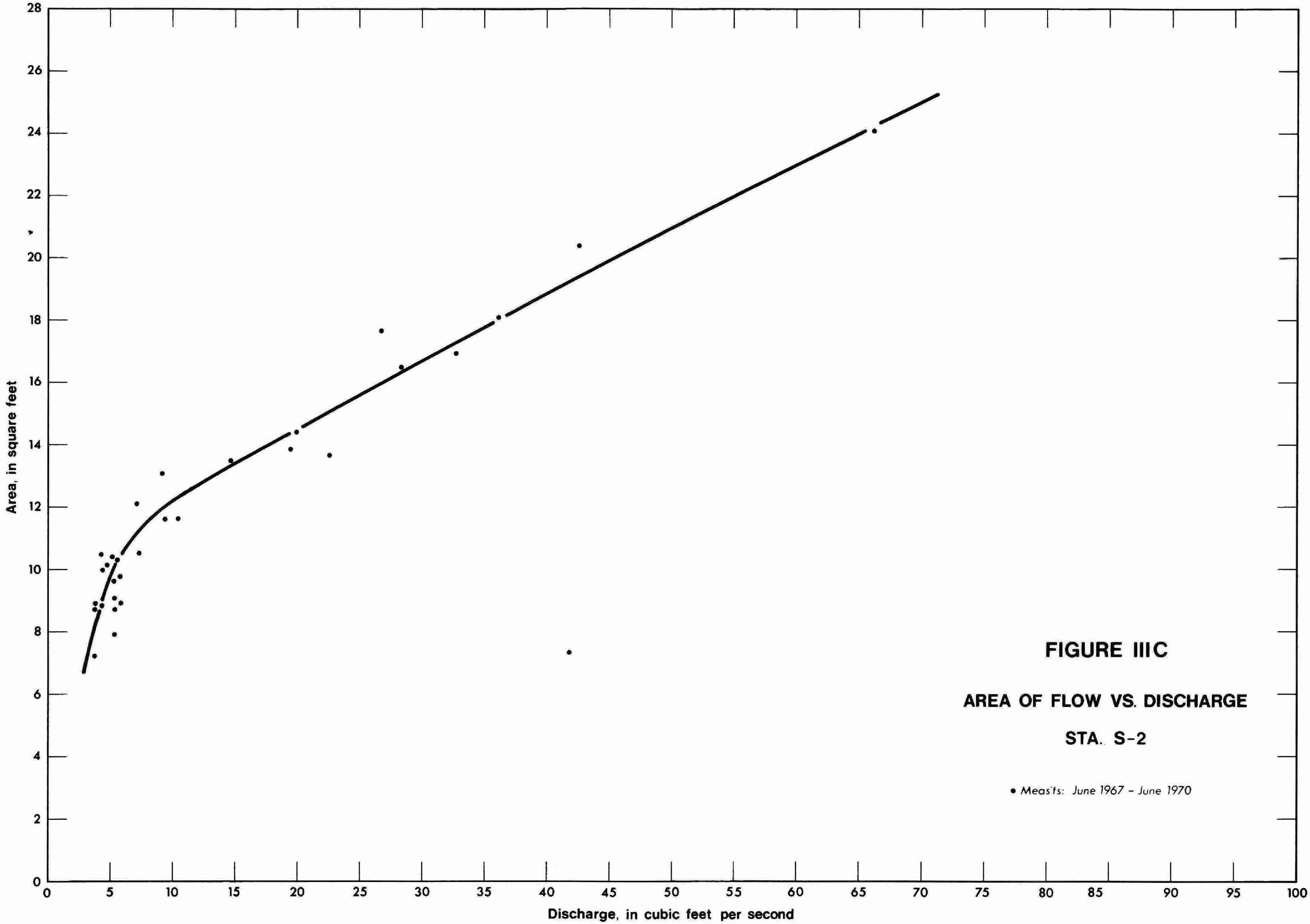


FIGURE IIIC
AREA OF FLOW VS. DISCHARGE
STA. S-2
• Meas'ts: June 1967 – June 1970
Area, in square feet
Discharge, in cubic feet per second
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
0
5
10
15
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25
30
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50
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60
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70
75
80
85
90
95
100

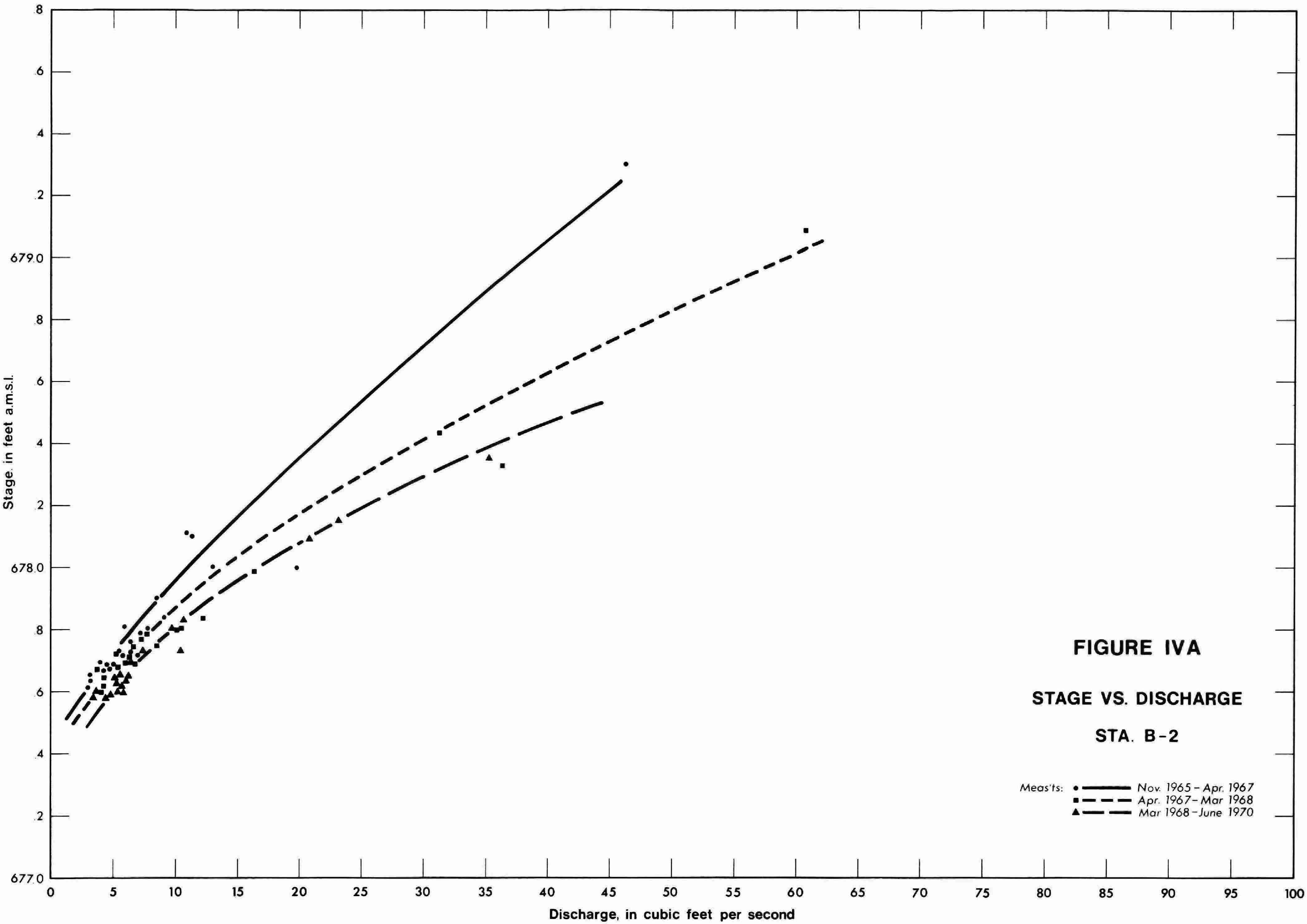

FIGURE IVA

STAGE VS. DISCHARGE

STA. B-2

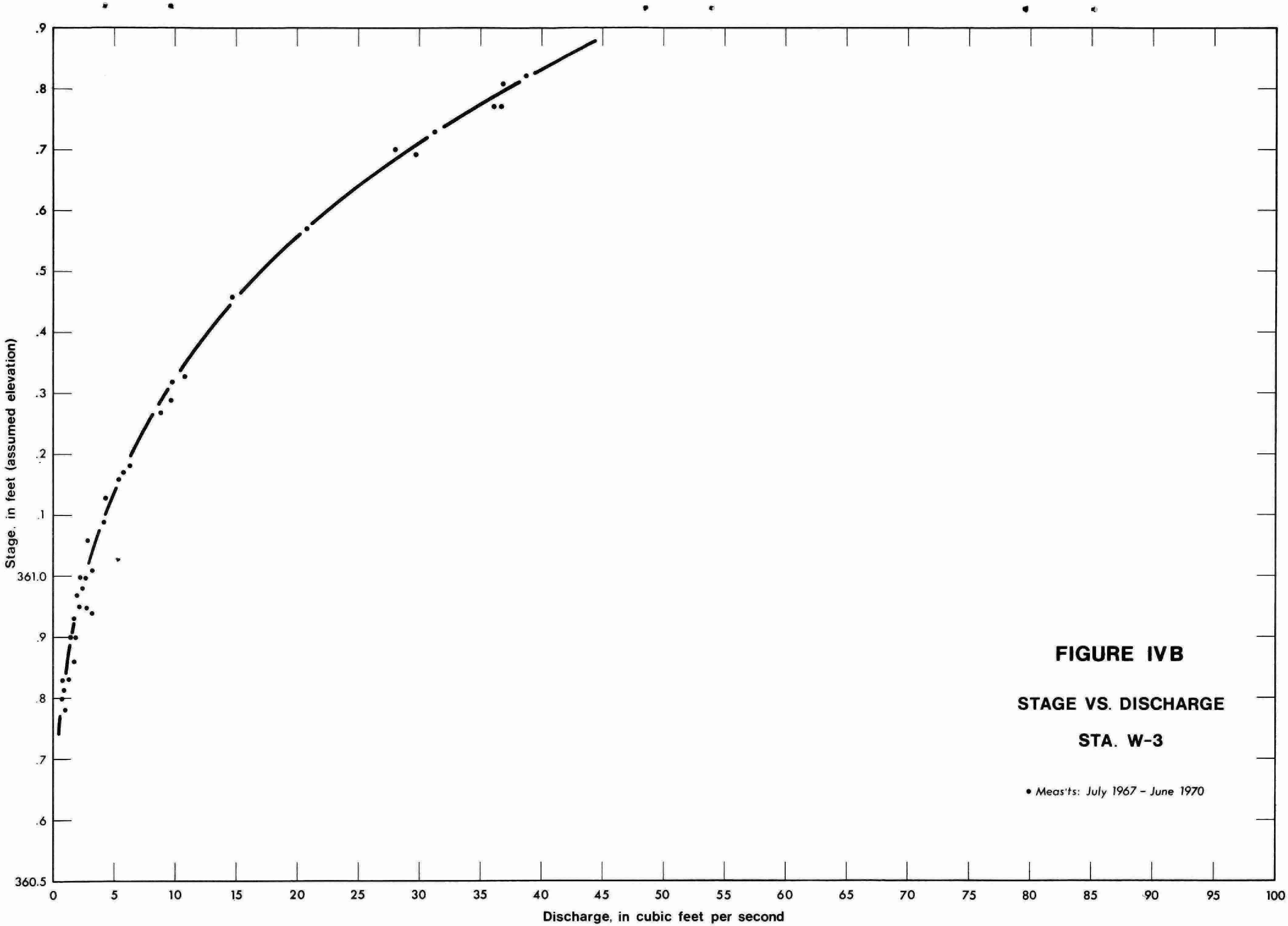
FIGURE IVB
STAGE VS. DISCHARGE
STA. W-3
• Meas'ts: July 1967 – June 1970
Stage, in feet (assumed elevation)
.9
.8
.7
.6
.5
.4
.3
.2
.1
361.0
.9
.8
.7
.6
360.5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Discharge, in cubic feet per second

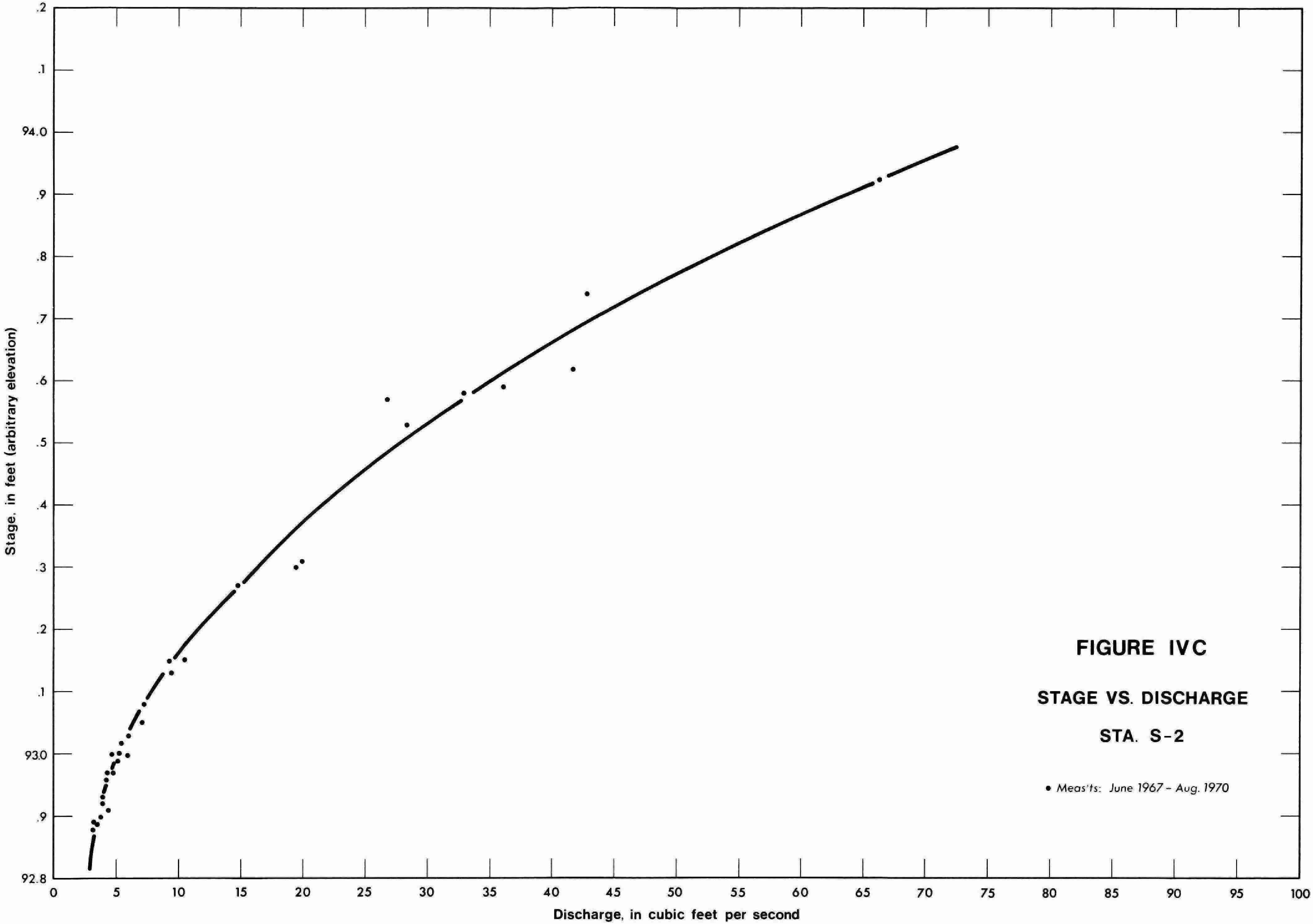

FIGURE IVC
STAGE VS. DISCHARGE
STA. S-2
• Meas'ts: June 1967 – Aug. 1970
Stage, in feet (arbitrary elevation)
Discharge, in cubic feet per second
92.8
.9
93.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
94.0
.1
.2
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100